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PRELIMINARY STUDY OF USING “PIPETRON”-TYPE MAGNETS FOR A PRE-ACCELERATOR FOR THE LHC

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Abstract

One of the luminosity limitations of the LHC is the rather low injection energy (0.45 TeV) with respect to the collision energy (7 TeV). The magnetic multipoles in the main dipoles at low field and their dynamic behaviour are considered to limit the achievable bunch intensity and emittance. We report on a preliminary study to increase the injection energy to 1.5 TeV using a two-beam pre-accelerator (LER) in the LHC tunnel. The LER is based on “Pipetron” magnets as originally proposed for the VLHC. The aim of the study is to assess the feasibility and to identify the critical processes or systems that need to be investigated and developed to render such a machine possible

MOTIVATION

A primary goal for the LER (Low Energy Ring) injector accelerator is to inject 1.5 TeV proton beams into the LHC, instead of the current injection scheme with 0.45 TeV SPS beam. At this new energy the field harmonics [1] of the LHC magnets are sufficiently satisfactory to prevent the luminosity losses. In addition to above, the LER may allow for implementation of a bunch coalescing technique (not possible with the SPS) leading to at least a factor of 4 in the LHC luminosity increase [2]. In the long term, the LER injector accelerator would greatly facilitate the implementation of a machine, which doubles the LHC energy (DLHC).

BASIC LAYOUT

We propose to install the LER accelerator inside the LHC tunnel (Figure 1), 1.35 m above the LHC. LER would accept 0.45 TeV proton beams from the SPS through the existing TI2 and TI8 transfer lines, and then accelerate the two beams to 1.5 TeV. The LER accelerator would be based on two-in-one super-ferric, combined-function magnets (Figure 2). These magnets were originally proposed for the VLHC Stage 1, a p-p collider in the US and were recently successfully tested at Fermilab [3-4].

Boundary conditions

In order to minimize the potential impact of the LER implementation process on the ongoing LHC physics program, the following LER design and construction criteria have been adopted:

- The LER accelerator will be installed in the LHC tunnel during regular LHC shutdowns.
- No new tunnel digging will be required.
- The current SPS-LHC beam injection scheme will remain intact and will be used “as-is” to inject beams into the LER ring. A reversal to the standard SPS-LHC injection will remain possible.
- The LER accelerator components will be designed and fabricated using as much as possible known technologies.

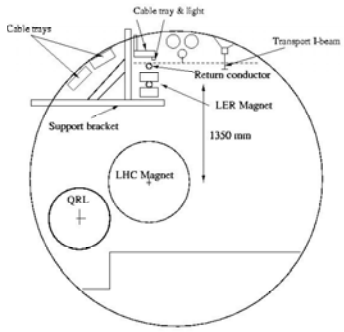

Figure 1. Position of the LER ring above the LHc

It is expected that the design and construction of the LER will take 5-6 years.

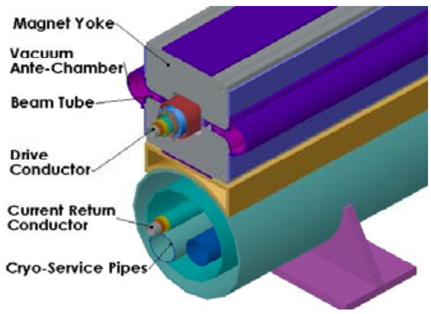

Figure 2. The original VLHC pipetron magnet in the VLHC configuration with the return conductor and cryo-service pipes below the magnet.

LER beam handling

In the new LHC beam injection scheme, the proton bunch stacking and the formation of the full intensity beam is performed in the LER ring. The beam passes through the LHC beam-pipe in several of LER/LHC straight sections. This means that in some straight sections the LER and the LHC accelerators share the same beam pipe. This scheme is being proposed to eliminate costly and time consuming digging of new bypass tunnels around the ATLAS and CMS detectors. Injection is using the existing LHC channels. In the straight sections 2, 3, 7 and 8, the two beams remain in independent LER beam pipes. The experiments in points 2 and 8 are supposed to be inactive during the runs with

LER. In Figure 3 the beam trajectory is schematically depicted.

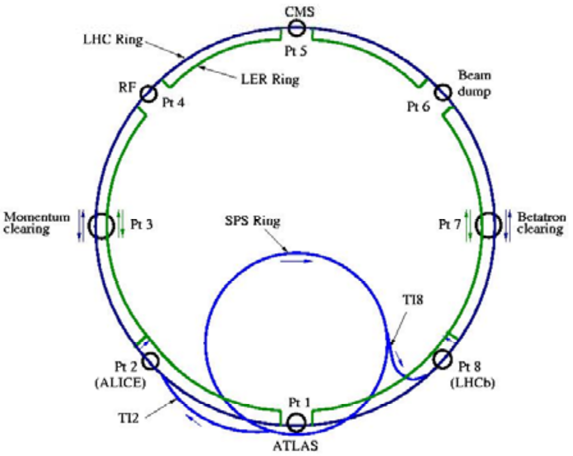

Figure 3. Layout of the two accelerator rings with common beam pipe in 4 straight sections

After stacking of the clock-wise and the counter-clock wise turning beams and acceleration to top energy, the beams are passed from LER into the full LHC ring using one of the bypass lines in the common straight sections in a single transfer mode. For this single transfer, only one set of the LER transfer line magnets need to be ramped down. The ramping down has to be done in a time period determined by the time interval between the tail and the head of the beam train (~ 87 microseconds).

LER LATTICE

A preliminary design of the LER optics [5] used the VLHC combined function magnets in order to replicate the LHC optics and match the LHC footprint. The dispersion suppressers were modelled on the ones of the Main Injector at Fermilab with 66 % of the magnet length and 75 % of the LER arc cell length. A list of arc and dispersion suppression cells for LER that allow to exactly reproduce the LHC lattice is shown in Table 1.

At the LER top energy field of 1.595 T, the required magnet current is 55 kA which is considerably lower than the current for the VLHC (89 kA for 1.966 T). The required LER gradient corresponds to +/- 3 %, as opposed to +/- 4 % for the VLHC. The lower field and gradient further improve the quality of the main arc magnets, as the operation is further away from the saturation region (around 1.9 T).

Table 1 Arc and dispersion suppressor magnets

Cell Type	Cell Length (m)	Magnet Type	Magnet Length (m)	Number per cell	B (T)	dB/dx (T/m)
Arc	107	GF/GD	12	8	1.595	4.858
Suppressor	80	GSF/GSD	8	8	1.595	10.112

The VLHC magnet gap is 20 mm. The preliminary LER lattice design [5] suggests that a 20 mm gap may be sufficient, but more detailed lattice simulations, including a beam impedance and a beam instability study [6], are needed to reach a more binding conclusion.

LER-LHC BEAM TRANSFER

Beam transfer from the LER ring into the LHC ring is the most challenging task of the LER proposal. The vertical separation of the LER and LHC rings can be made to be 135 cm. This means that the 1.5 TeV beam needs to be bent down (or up) out of the LER (or LHC) ring, transported, and then bent into the LHC (or LER) ring over a vertical distance of 135 cm. About half of this distance, 67.5 cm, is needed to clear any LHC magnets. The LER-LHC transfer line magnets must use only the magnet free sections between D1 and Q5 in the LHC. The proposed design assumes that the beam transfer is made using 4 bends, each with a bending power of 168 Tm. (Figure 4).

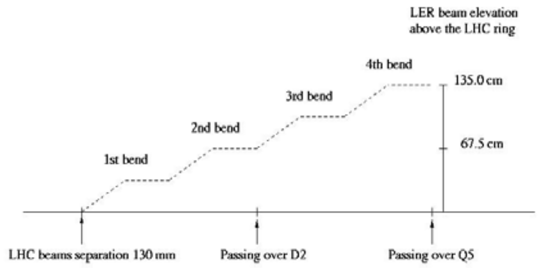

Figure 4. Beam transfer LER-LHC, 4 bends are used to get clear of the LHC magnets.

Once the LER beam has cleared these magnets it will not be difficult to transfer the beam into the LER ring. The operation of clearing the LHC magnets must take place necessarily within the available free space of the straight sections so the transfer line magnets can reside at the LHC ring level. A preliminary LER lattice design [5] was made to produce the footprint as close as possible to that of the LHC to preserve the best possible beam quality in the LER ring and in the LER-LHC beam transfer operation. The VLHC and LHC magnets have a horizontal beam separation of 150 mm and 194 mm, respectively. The beam transfer is done in both horizontal and vertical planes. A preliminary layout of the LHC-LER beam transfer is shown in Figure 5. The LHC-LER transfer line study [5] indicates necessity to increase the clock-wise and counter clock-wise beams separation as early as possible in order to preserve high quality beam optics in LHC-LER transfer line. For that reason the D1 dipole has been split into two dipoles (D1A and D1B, each of ~8 m length, and ~8 T field) inducing about 130 mm beam separation at the exit of D1B. A new high-field, large bore magnet technology [7] based on the Nb3Sn conductor suggests a plausible feasibility of fabrication the D1A and D1B magnets, especially that the larger bore HD1B, if split to 2 parts (D1B_1 and D1B_2) of longer length, will use ~ factor 2 lower B-field. The first vertical bend is arranged using three sets of magnets. The first set consists of fast pulsing pairs of single bore magnets which, when turned off, allow the beam to pass into the

LHC ring. A beam drift space after the first set of magnets is created to allow for the LER and LHC beam pipe separation. The second set consists of pairs of normal-conducting magnets, which can be placed just above the LHC beam pipe. The third set consists of two-bore, high-field superconducting magnets to complete the first bend. The 2nd, 3rd and 4th bends consists of two-bore, high-field superconducting magnets. In the horizontal plane the clock-wise and the counter-clock LHC beams have no separation at D1, but they are separated by 194 mm at D2. The first magnet pair of the first vertical bend section is placed at a location that the clock-wise and counter-clock beams are separated by ~130 mm. A short, horizontal dipole is placed in front of a second vertical magnet set to produce 150 mm beam separation of the LER accelerator. A 20 m long drift space after the V7 magnet string is for the quads and other correctors.

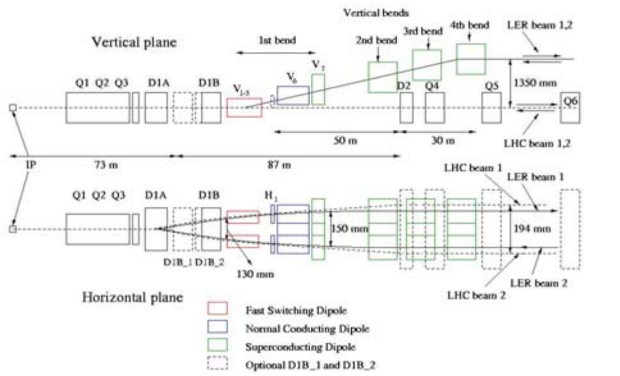

Figure 5. A preliminary arrangement of the LER-LHC transfer line magnets.

In order to understand the choice and arrangement of the magnets in the first bend we must look at the timing sequence of the SPS-LER-LHC beam transfer scheme. This is schematically indicated in Figure 6.

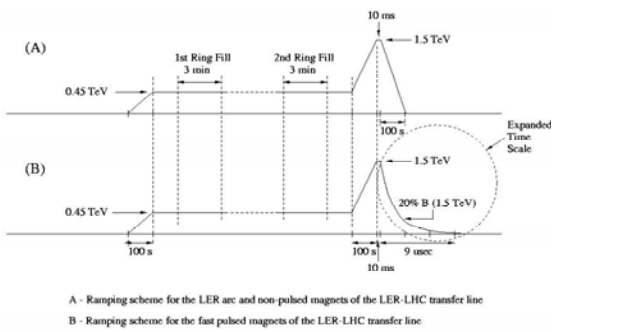

Figure 6. Timing scheme for the LER-LHC beam transfer

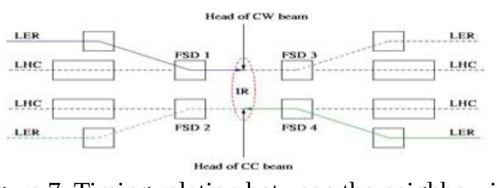

Figure 7. Timing relation between the neighbouring fast switching magnets.

When the SPS is ready for beam transfer, all LER magnets, including those in the transfer lines, are ramped at 100 s rate to the required fields for the 0.45 TeV beam. The stacking of the first SPS beam begins and it lasts for about 3 min. Then the stacking of the 2nd SPS beam begins and lasts for about 3 min as well. As soon as the stacking of the second beam is completed the LER magnets ramp to 1.5 TeV, again in 100 s. The 1.5 TeV beams may circulate for 10 ms or so to stabilize, and then the fast switching LER-LHC transfer line dipoles (FSD's) are turned off, forcing the beams to circulate from then on in the LHC rings only. At this point all remaining LER magnets are ramped down. However, as shown in Figure 7, the FSD 1 (FSD 4) magnets must stay ON for a duration of the beam train (~ 87 microseconds) after FSD 2 (FSD 3) were turned off. All fast switching magnets of the first bend will have to be turned off during the passing of the ~ 3 μs long beam gap. A study [8] is ongoing into the design of a magnet with a single cos θ shaped conductor and flux containing cores using thin Fe3%Si lamination. Such a magnet can have an inductance of ~ 1 micro-Henry for a length of ~ 1 m. The conductors should be made out of 99.999 % pure OFHC copper and operate at temperatures below 20 K. Part of the powering circuit will also be located at low temperatures. A minimal distance of ~130 mm between the bore centres of the FSD magnet pair is sufficient to suppress a possible cross-talk of their magnetic flux.

CONCLUSIONS

A preliminary layout for the lattice and the beam transfers has been found. The new D1 magnets as well as the fast switching magnets of the LHC-LER transfer line can be made using known technologies. More studies are needed on the beam stability and the impedance to prove the viability of the LER concept.

REFERENCES

[1] LHC Design Report Vol 1, O. Brunning et al., CERN-2004-003, Section 4.7 Dynamic aperture.

[2] T. Sen, private communication, 2006

[3] Design Study for a Staged VLHC, Fermilab-TM-2149, 2001

[4] H.Piekarz, Test of 2 T Superconducting Transmission Line Magnet System, presented at MT-19, *IEEE Trans. Appl. Supercond.* (2006), in press.

[5] J. Johnstone, Preliminary design of the LER lattice and the LHC-LER transfer line, work in progress, also EPAC, 2006

[6] Vl. Shiltsev, Preliminary study of beam impedance and instabilities for the LER, work in progress, 2006

[7] A. Devred et al., IEEE Transactions on Apllied Superconductivity, Vol. 15, No 2, June 2005

[8] S.Hays, Y.Huang, Va. Kashikhin and H. Piekarz, Preliminary study of the fast switching magnet design for the LER transfer line, work in progress, 2006